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(54) Decoding colour video signals for display

(57) A video display apparatus receives a transmitted colour video signal coded using three system primaries Rs, Gs, Bs and decodes the signal for display on a device using four display primaries. The four display primaries are independent, in that no display primary can be expressed as a combination of another two display primaries, and so define a quadrilateral in a chromaticity diagram. A fifth, imaginary display primary is determined as a linear combination of the third and fourth display primaries and the quadrilateral divided into triads defined respectively by the first, fourth and fifth, first, fifth and second, and second, fifth and third display primaries. The received video signal is decoded by three matrix arithmetic units 12, 14, 16, one for each triad, and drive signals for the first to fourth display primaries calculated. For each pixel, an arithmetic unit output producing no negative display drive signals is then selected and its output switched by switches 20, 22, 24 to drive a four-primary display device 2.

This arrangement improves colour rendition in HDTV systems, and the 4 display primary colours are R(620nm), B(460nm), G(514nm) and G(540nm).

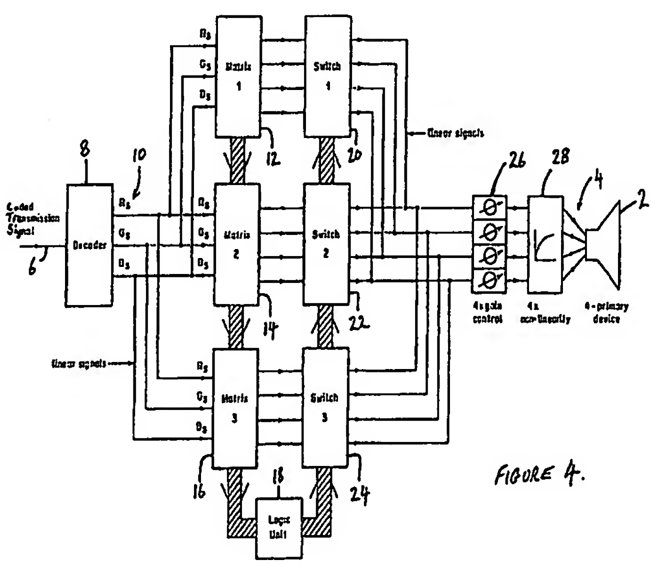

FIGURE 4.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1990.

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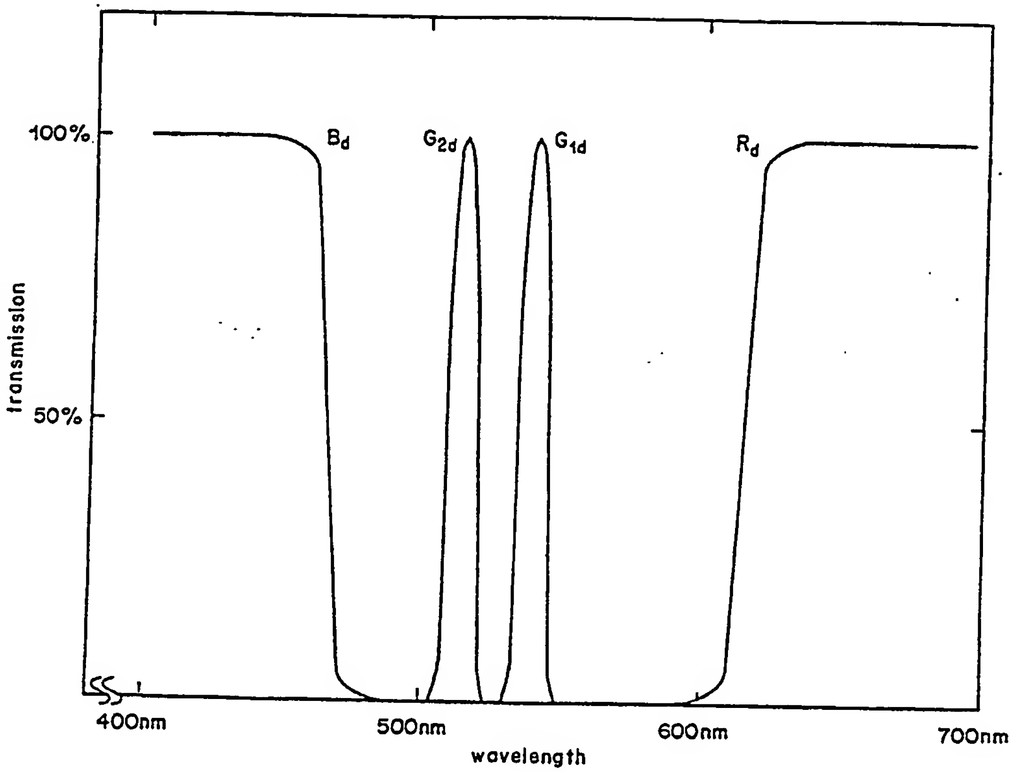
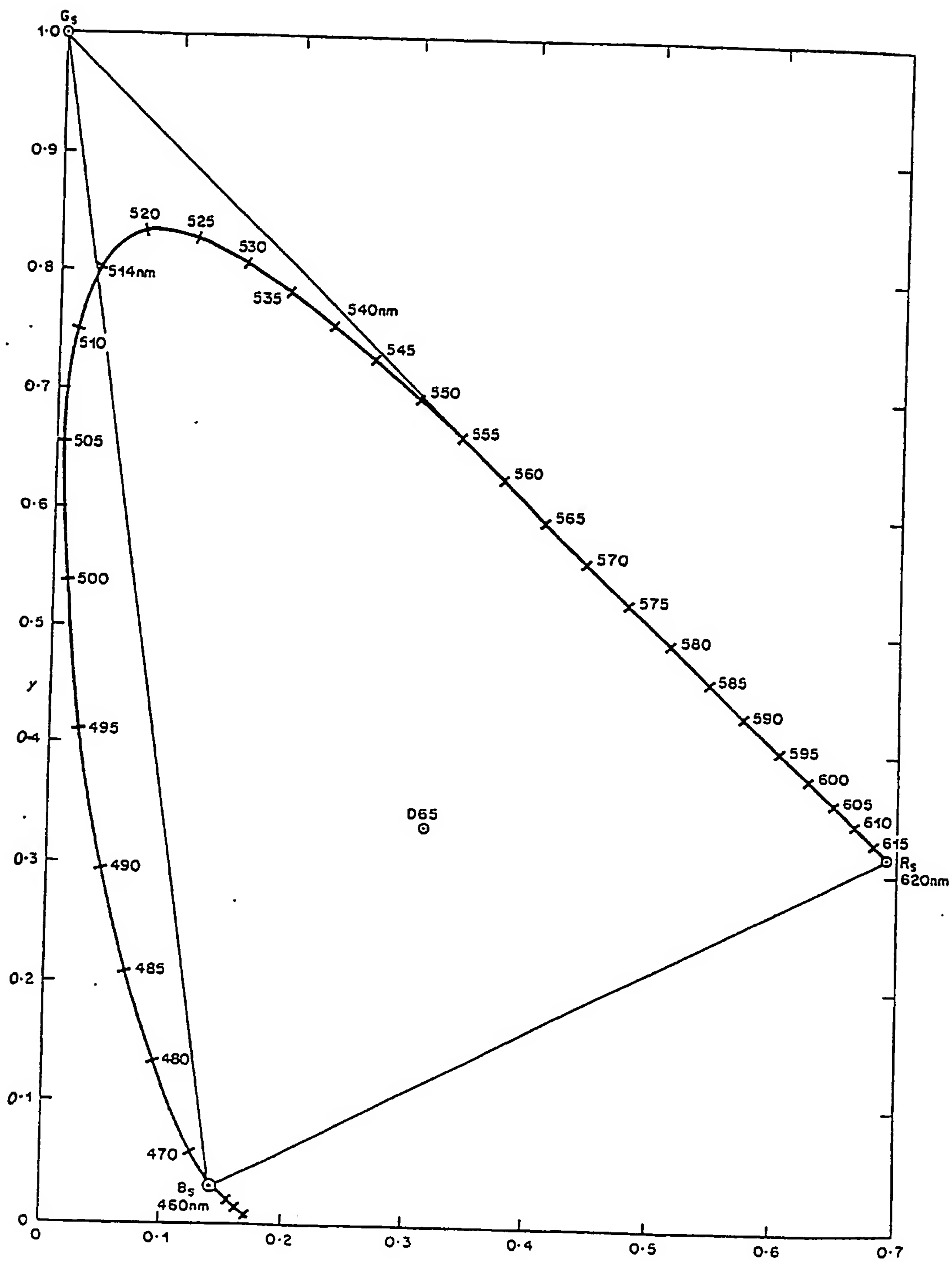
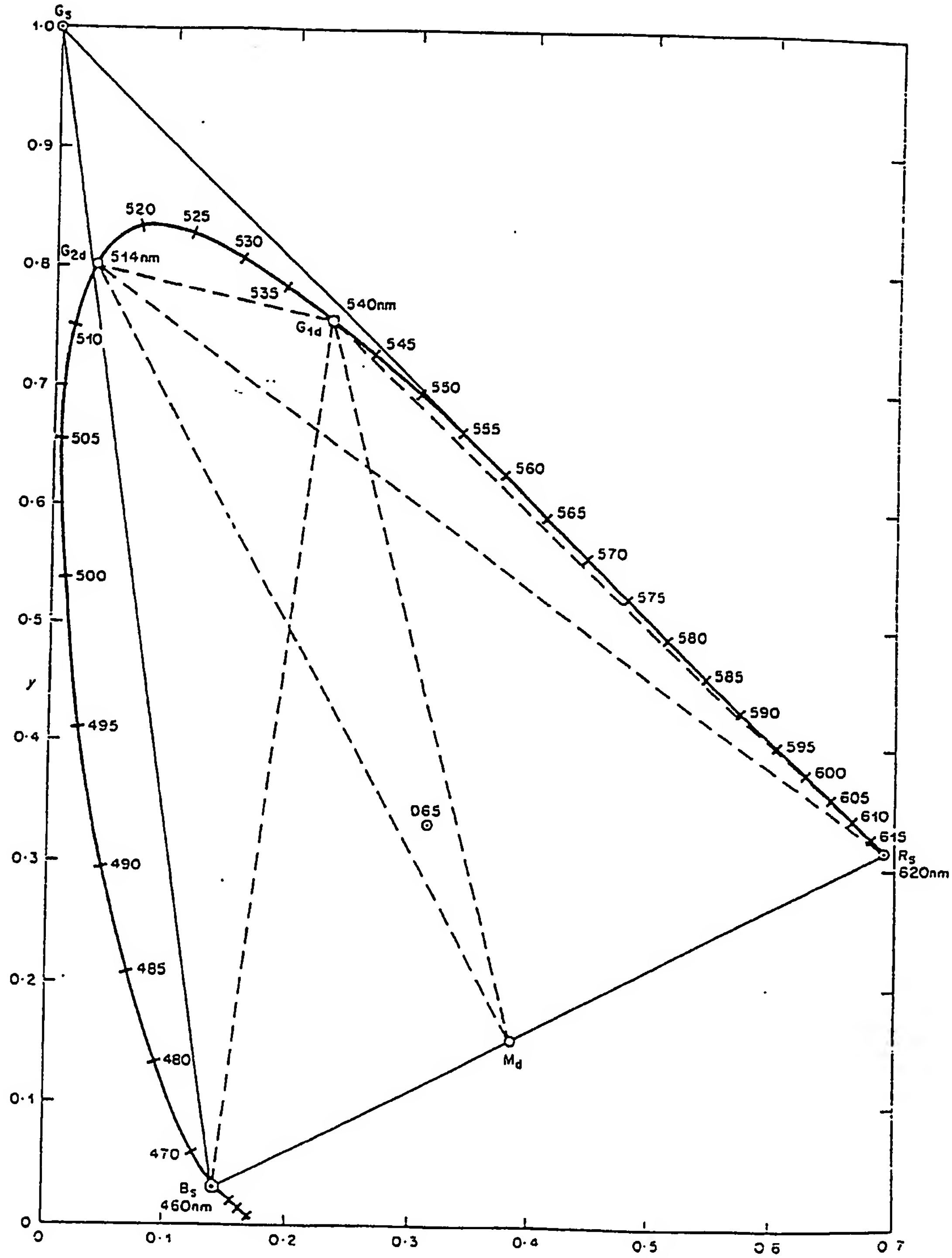

100%
50%
transmission
B_d
G_{2d}
G_{1d}
R_d
400nm
500nm
600nm
700nm
wavelength

FIGURE 1



Gs
1·0
0·9
0·8
0·7
0·6
0·5
y
0·4
0·3
0·2
0·1
0
520
525
530
514nm
535
540nm
510
545
550
505
555
560
565
570
500
575
580
585
495
590
595
600
605
D65
610
615
Rs
490
620nm
485
480
470
Bs
460nm
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7

FIGURE 2



Gs
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
y
520
525
530
535
540nm
G2d
514nm
G1d
510
505
500
495
490
485
480
470
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
Rs
620nm
D65
Md
Bs
460nm
0
0·1
0·2
0·3
0·4
0·5
0·6
0·7

FIGURE 3

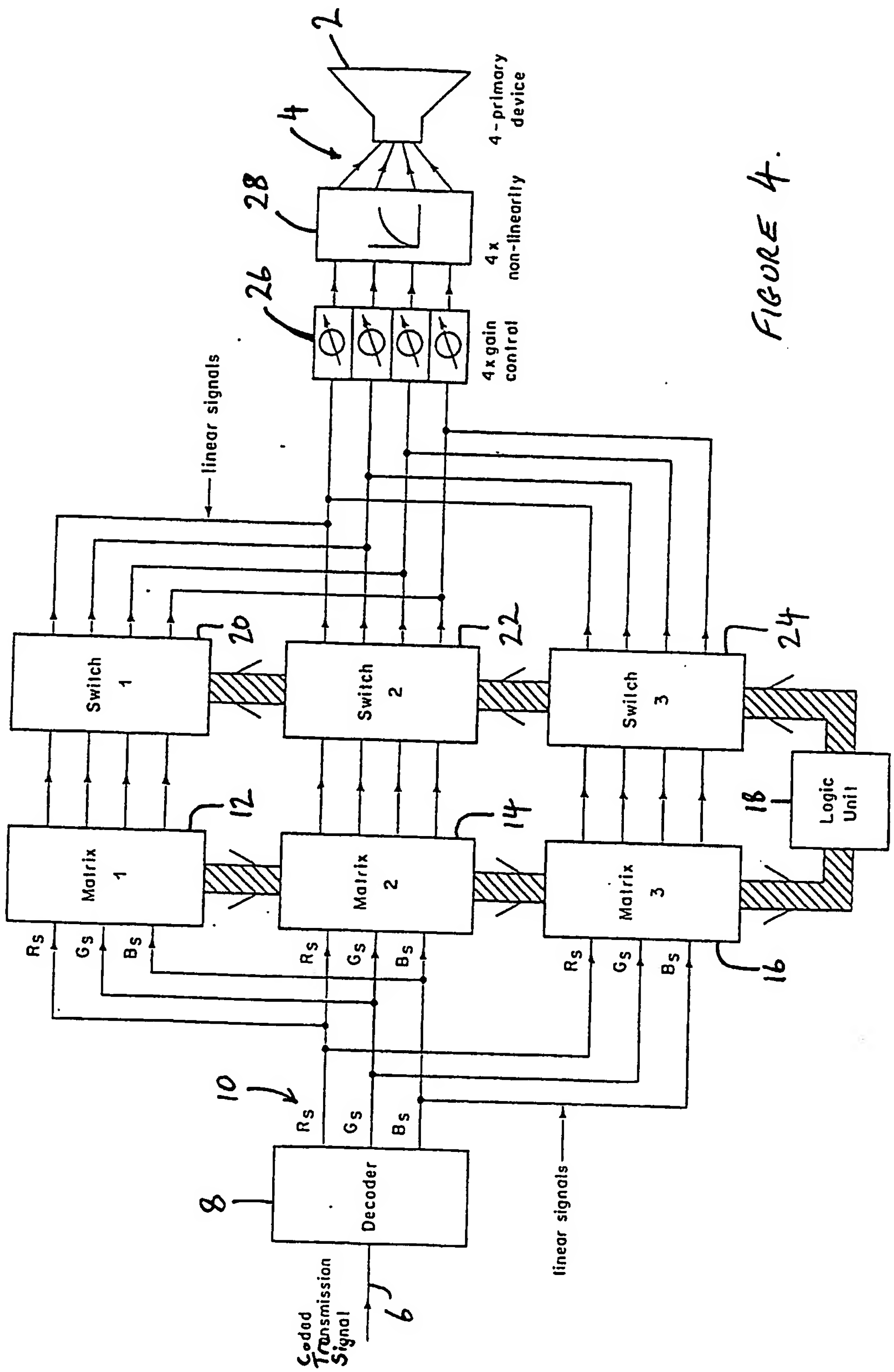
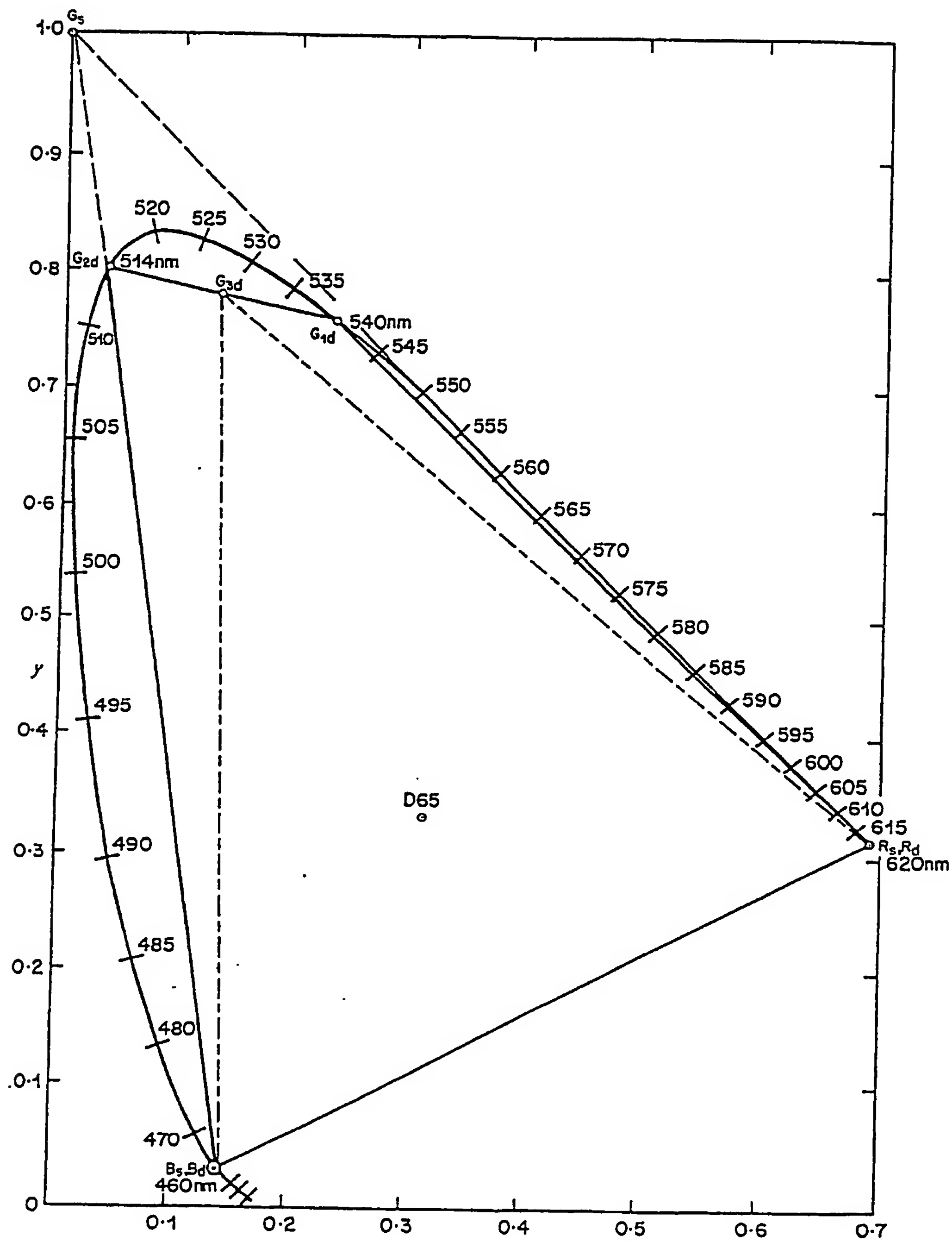

2
4-primary device
4
28
4 x non-linearity
26
4 x gain control
linear signals
Switch 1
20
Switch 2
22
Switch 3
24
Matrix 1
12
Matrix 2
14
Matrix 3
16
Logic Unit
18
Rs
Gs
Bs
10
8
Decoder
Coded Transmission Signal
6

FIGURE 4.



G_s
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
y
520
525
530
535
G_{2d}
514nm
G_{3d}
540nm
G_{1d}
545
510
550
555
505
560
565
570
500
575
580
585
495
590
595
600
605
D65
610
615
490
R_s, R_d
620nm
485
480
470
B_s, B_d
460nm
0·1
0·2
0·3
0·4
0·5
0·6
0·7

FIGURE 5

6/8

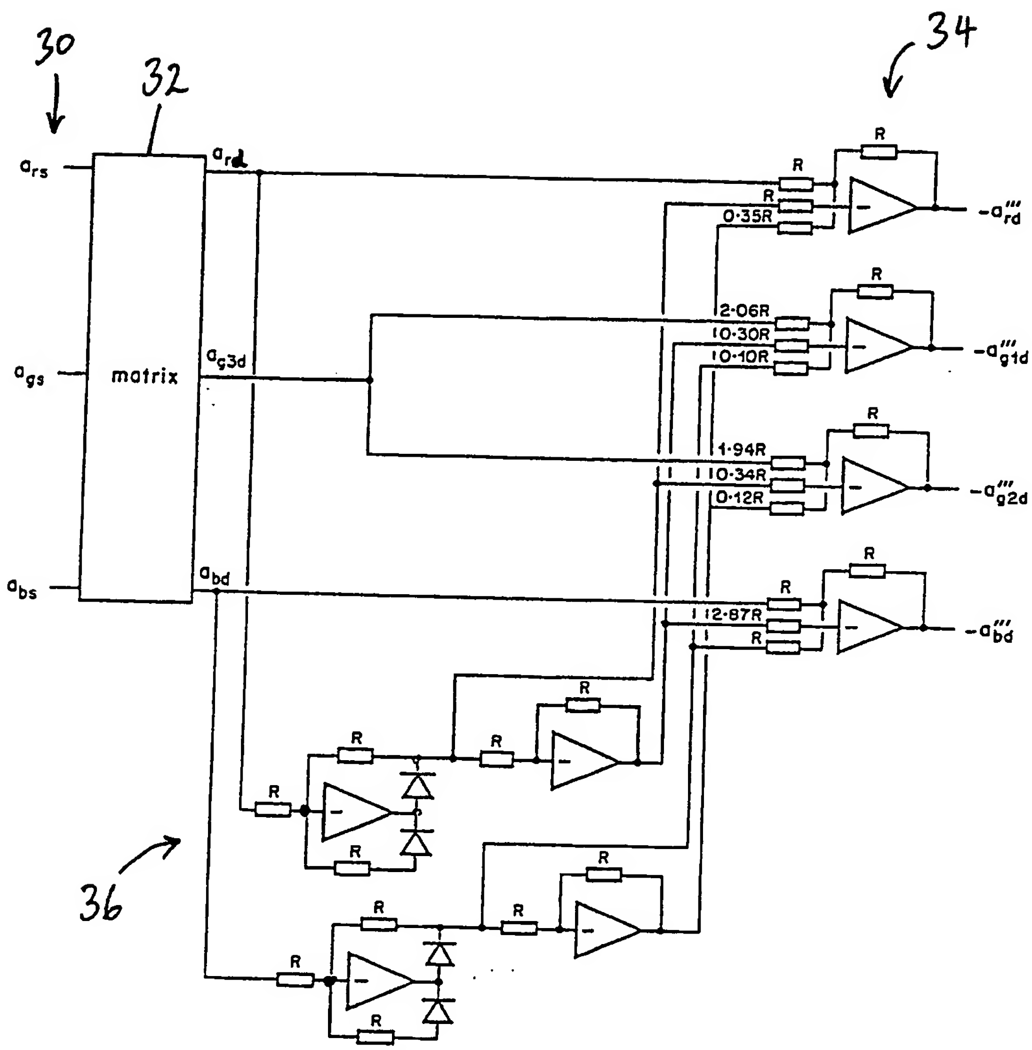
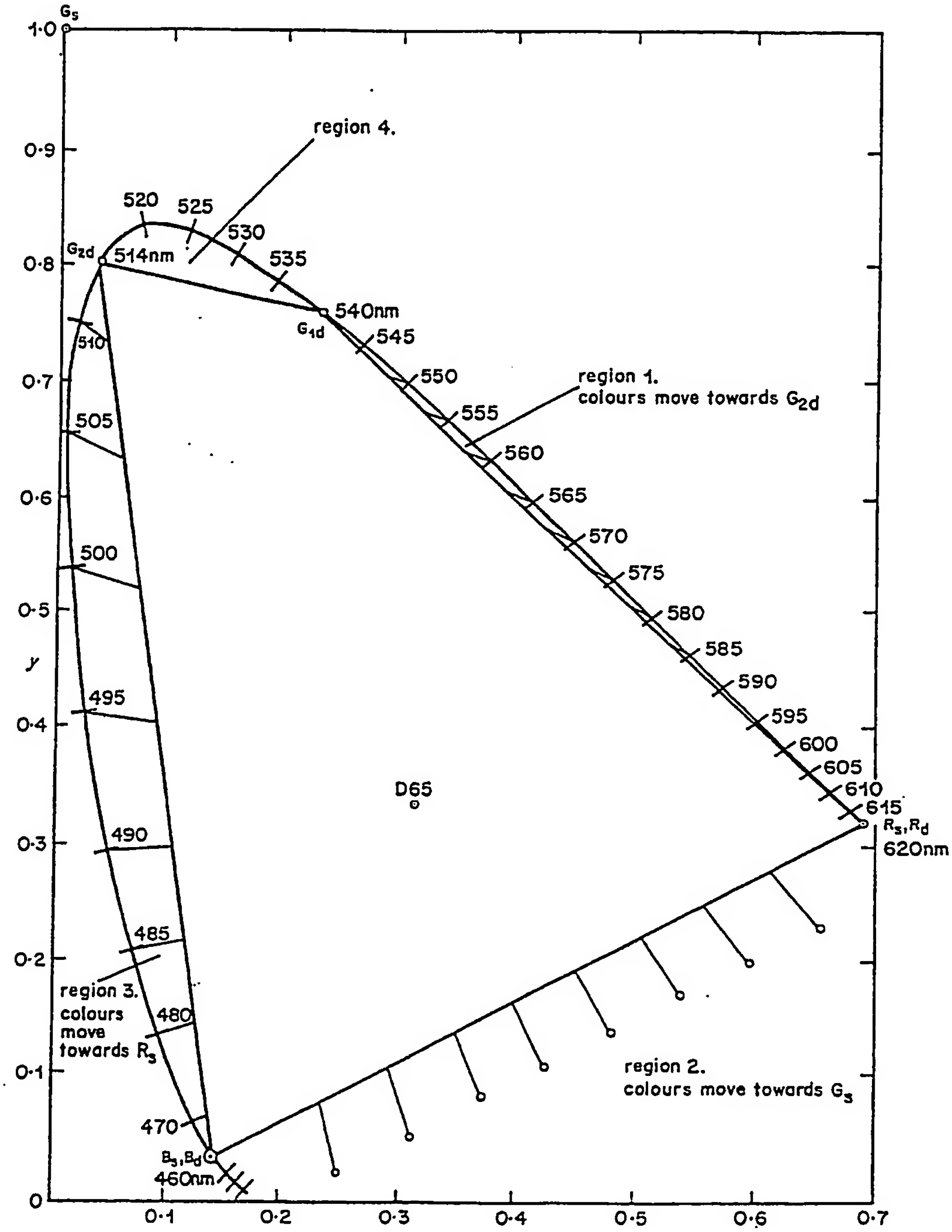
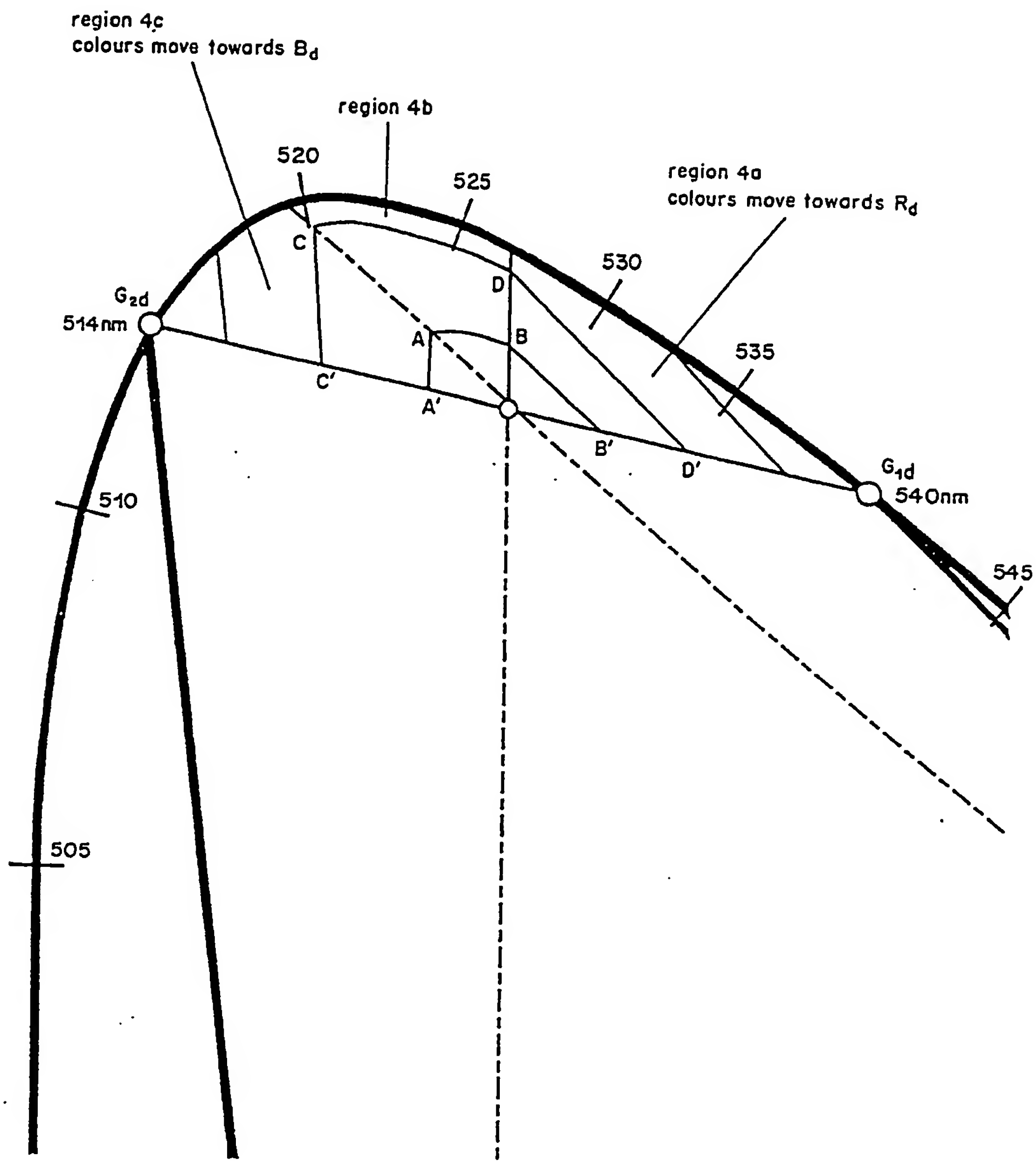

30
32
34
36
a_{rs}
a_{gs}
a_{bs}
matrix
a_{rd}
a_{g3d}
a_{bd}
R
0·35R
2·06R
10·30R
10·10R
1·94R
10·34R
0·12R
12·87R
$-a'''_{rd}$
$-a'''_{g1d}$
$-a'''_{g2d}$
$-a'''_{bd}$

FIGURE 6



Gs
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
y
region 4.
520
525
530
535
G2d
514nm
540nm
G1d
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
Rs,Rd
620nm
510
505
500
495
490
485
480
470
Bs,Bd
460nm
region 1.
colours move towards G2d
D65
region 3.
colours
move
towards Rs
region 2.
colours move towards Gs
0·1
0·2
0·3
0·4
0·5
0·6
0·7

FIGURE 7



region 4c
colours move towards B_d
region 4b
520
525
region 4a
colours move towards R_d
C
D
530
G_{2d}
514nm
A
B
535
C'
A'
B'
D'
G_{1d}
540nm
510
545
505

FIGURE 8

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METHOD AND APPARATUS FOR DECODING COLOUR VIDEO SIGNALS FOR DISPLAY

This invention relates to a method and apparatus for decoding colour video signals for display.

The colorimetry of television displays has been a relatively stable field, in which there have been fairly few developments since the move from black-and-white to colour in the late 1960s. Recently, however, there has been a resurgence of interest in research associated with television colorimetry, prompted by the development of new HDTV standards. A possible colorimetric coding system has been proposed in BBC Research Department Report 1990/2 published by BBC Research Department, Kingswood Warren, Tadworth, Surrey KT20 6NP, England, which describes a television system having one or more system primaries which cannot be realised in a practical display device because they are spectral or super-spectral. This system provides for a wider colour gamut and the use of true constant-luminance operation without unduly sacrificing compatibility with existing CRT (cathode ray tube) display. Thus, it would be possible to introduce a new HDTV or enhanced PAL service, operating with the improved colorimetric coding, without introducing excessive colour errors into the pictures displayed by receivers already in use.

In addition, the use of a coding method having a degree of compatibility with present-day displays results in the ability to monitor the pictures produced in the television studio while minimising the additional complexity that must be introduced into the display to achieve the necessary accuracy.

A display monitor in such a system is able to reproduce accurately the range of colours coded by the new system only within the triangle defined by its display phosphors. The gamut of the system itself, however, is considerably larger than this, and embraces all of the

presently-available real surface colours and a substantial proportion of the complete colour spectrum. If full advantage is eventually to be taken of this enlarged colour gamut, it will be necessary to develop new display techniques able to reproduce a wider range of colours.

The invention provides a method and apparatus as defined in the appendant independent claims. Preferred features of the invention are defined in the dependent subclaims.

In a television system having one or more system primaries which cannot be realised in a practical display device because they are spectral or super-spectral, using the method and apparatus according to the invention it may be possible to display much of the colour gamut of the system by using more independent display primaries than independent transmission primaries (independent meaning that no primary can be matched by a combination of positive multiples of the other primaries).

At the present time, such an option could only be achieved in a CRT display by reducing the size of the mask apertures in the CRT shadow mask, and hence might be at the expense of a reduced electron-beam transmission efficiency. All other factors being equal, this could result in a lower light output; in addition, phosphors of the correct chromaticity would need to be manufactured, bearing in mind the other parameters (for example, low lag) that must be satisfied at the same time. This situation may not always persist, however. Projection displays (even those based on CRTs) are subject to different constraints to shadow-mask displays; use of four or more, rather than three, display tubes may even enhance the final brightness under these circumstances. Liquid-crystal displays, whether projection or direct-view, rely on an external source for the production of the emitted light, the colour being determined by suitable optical filtering. Illumination is either broadband or else by a series of narrow spectral lines produced by discharge lamps or phosphor excitation. Such techniques can allow a much

freer choice of display colour parameters. For example, Figure 1 shows the characteristics of four colour filters which, when used to shape the wavelength spectrum produced by a normal quartz-halogen light source, are capable of producing primaries very close to the wavelengths 460, 514, 540 and 620 nm.

The selection of the colour primaries for an enhanced-colour-gamut display is only the first step in the complete process, however. It is also necessary to decode the incoming television signal into the drive signals for each of the display colours. This presents an interesting mathematical exercise, since there are only three incoming signal components - the luminance and two colour difference signals - from which it is necessary to derive, for example, four display signals. The process is therefore equivalent to solving three simultaneous equations in four unknowns and, in general, there are an infinite number of possible ways of achieving any particular displayed colour within the permissible gamut.

In order to define a unique set of display drive voltages for each incoming combination of RYB signals, therefore, it is necessary to impose an additional, somewhat arbitrary, set of constraints. A number of examples of such constraints and the solutions to which they lead are set out herein in the descriptions of specific embodiments of the invention.

Specific embodiments of the invention will now be described by way of example, with reference to the figures in which:-

Figure 1 shows the characteristics of four colour filters for filtering a quartz-halogen light source to produce four primaries;

Figure 2 is a CIE diagram showing the system primaries and white point for the HD (High Definition) Eureka system;

Figure 3 is the CIE diagram of Figure 2, also showing two green display primaries;

Figure 4 shows a block diagram of an implementation

of a 4-primary display;

Figure 5 is a CIE diagram showing three green display primaries, one being a linear mixture of the other two;

Figure 6 shows a decoding circuit for decoding four display drive signals;

Figure 7 is a CIE diagram showing the regions outside the colour quadrilateral of Figure 5; and

Figure 8 shows region 4 of Figure 7 in more detail.

1. Introductory theory

The three primaries of a proposed High Definition television system known as the Eureka system are shown in Figure 2 which is a CIE 1931 chromaticity diagram, together with the spectrum locus and the balance point, D65, at which the three system primary signals are all equal to unity. The red is sited at 620 nm, blue at 460 nm. It can be seen that the "green" primary is unreal and therefore cannot be displayed by ANY means. For display purposes only this non-real transmission green may be replaced with two real greens, and the necessary four primary analysis applied to drive the four real primaries. The two greens chosen for this exercise are shown in Figure 3 as Green 1 at 540 nm and Green 2 at 514 nm. These wavelengths were chosen to maximise the displayable colour area.

The colour equation of a display using the system primaries is shown in Equation 1a which relates the system signals Rs Gs and Bs to the tristimulus values of the emitted light, X Y and Z

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad 1a$$

where the values X Y and Z are the tristimulus values of the light in the CIE 1931 colour space. Any other colour space can be used, CIE 1931 is convenient since the Y signal represents the true luminance of the colour in question.

The system matrix [Ms] is a 3 by 3 matrix of the tristimulus values of the system primaries in CIE 1931

space, which is derived by standard means as shown below in Section 2. The relationship between the system signals and the light entering a theoretical camera using these system primaries is:

$$\begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix}^{-1} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$= \begin{bmatrix} & & \\ & Mt & \\ & & \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad 1b$$

The transmission matrix [Mt] is another 3 by 3 matrix, of the tristimulus values of the CIE primaries in the colour space defined by the system primaries Rs Gs and Bs.

The analysis of a four primary display is strictly insoluble, Equation 1c shows the relationships between light output and display primaries:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Md & \\ & & \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G1d \\ G2d \\ Bd \end{bmatrix} \qquad 1c$$

The matrix, [Md], is a 3 by 4 matrix of the tristimulus values of the display primaries, again in CIE 1931 colour space. Thus Equation 1c can be expanded into Equation 1d:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Xr & Xg1 & Xg2 & Xb \\ Yr & Yg1 & Yg2 & Yb \\ Zr & Zg1 & Zg2 & Zb \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G1d \\ G2d \\ Bd \end{bmatrix} \qquad 1d$$

The tristimulus values of the display primaries are not known at this stage, but they are linearly related to the chromaticity coordinates of the primaries in the CIE 1931 colour space, thus Equation 1d expands to become Equation 1e:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1*xr & m1*xg1 & m2*xg2 & n*xb \\ 1*yr & m1*yg1 & m2*yg2 & n*yb \\ 1*zr & m1*zg1 & m2*zg2 & n*zb \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G1d \\ G2d \\ Bd \end{bmatrix} \qquad 1e$$

The linear scalers 1,m1,m2 and n can be found by balancing the system to its white point. In this instance the white point is illuminant D65, thus at the balance point:

$$\begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} = \begin{bmatrix} l*xr & m1*xg1 & m2*xg2 & n*xb \\ l*yr & m1*yg1 & m2*yg2 & n*yb \\ l*zr & m1*zg1 & m2*zg2 & n*zb \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \qquad 1f$$

This equation presents a problem since there are four unknowns and only three equations, thus there is an infinite number of solutions. An aspect of the present invention provides a method of overcoming this problem. The method involves dissecting the colour quadrilateral into overlapping or non-overlapping triangles.

2. <u>Standard three-primary analysis method</u>

For a conventional tri-colour system in which the system and display use the same set of primaries, the relationships between light input, transmission signals and light output are shown in Equations 1a and 1b above. In order to derive the system matrix [Ms] it is necessary to invoke a fourth colour at which the system signals are all equal to unity (Rs=Gs=Bs=1), thus the display equation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

becomes, at balance:

$$\begin{bmatrix} Xw \\ Yw \\ Zw \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} . \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \qquad \text{2b}$$

where Xw Yw and Zw are the tristimulus vales of the balance point or white (usually illuminant D65). This is an expression of one of Grassman's laws, which states that any colour can be matched by linearly mixing any three other colours provided that none of these can be matched by linearly mixing the other two colours.

The display matrix [Ms] is comprised of the tristimulus values of the system primaries, as yet unknown:

$$\begin{bmatrix} Xw \\ Yw \\ Zw \end{bmatrix} = \begin{bmatrix} Xr & Xg & Xb \\ Yr & Yg & Yb \\ Zr & Zg & Zb \end{bmatrix} . \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \qquad \text{2c}$$

but since the tristimulus values are proportional to the chromaticity coordinates:

$$\begin{bmatrix} Xw \\ Yw \\ Zw \end{bmatrix} = \begin{bmatrix} 1*xr & m*xg & n*xb \\ 1*xr & m*yg & n*yb \\ 1*zr & m*zg & n*zb \end{bmatrix} . \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \qquad \text{2d}$$

where 1 m and n are unknown constants of proportionality. Equation 2d yields three equations in three unknowns and can thus be solved. The inverse of the resulting matrix gives the transmission matrix for Equation ib.

The display matrix [Ms] is made up of the tristimulus values of the display primaries, in CIE 1931 space. The middle row of the matrix defines the luminance equation for these primaries. The act of "balancing" a practical display device to the illuminant (D65) results in the actual display primaries having luminances each proportional to the relevant value in the luminance equation, no other values will do this.

If the display primaries are not identical to the system primaries, then two solutions are required, one for the system primaries, the other for the display primaries, and a transfer matrix is derived by multiplication, as shown below.

For the system primaries:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix}^{-1} . \begin{bmatrix} Z \\ Y \\ Z \end{bmatrix} \qquad \text{2e}$$

For the display primaries:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Md & \\ & & \end{bmatrix} . \begin{bmatrix} Rd \\ Gd \\ Bd \end{bmatrix} \qquad \begin{bmatrix} Rd \\ Gd \\ Bd \end{bmatrix} = \begin{bmatrix} & & \\ & Md & \\ & & \end{bmatrix}^{-1} . \begin{bmatrix} Z \\ Y \\ Z \end{bmatrix} \qquad \text{2f}$$

And the relationship between them is:

$$\begin{bmatrix} Rd \\ Gd \\ Bd \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} . \begin{bmatrix} & & \\ & Md & \\ & & \end{bmatrix}^{-1} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \text{2g}$$

The matrix product can be evaluated as a transfer matrix [Mx] by conventional matrix multiplication and becomes a simple 3 by 3 linear matrix to be fitted in the receiver.

Again, this matrix comprises the tristimulus values of the system primaries in the colour space defined by the display primaries. Thus if any display primary is equal to the corresponding system primary, then its column in the matrix will be linearly scaled to the appropriate column of the ident matrix, the scaling being equal to the ratio of the luminances of this primary in the two balanced conditions; if all the display primaries equal the system primaries the matrix is the ident matrix.

Any colour reproduced by this receiver, lying in the colour gamut common to the two triangles formed by the system primaries and the display primaries, will be portrayed correctly. It should be noted here that this assumes matrix operations on linear signals only; any non-linearity (gamma) must be removed and re-applied after matrix conversions. It is possible to apply matrix arithmetic to non-linear signals, but the matrices will generally be different from those described here and will only produce approximate results.

The systems described by equations 2e to 2g may each be balanced to the same illuminant, or may be separately balanced to two different colours. For example, although the standard PAL domestic system is notionally balanced to D65, it is common practice to balance studio and outside broadcast cameras to the prevailing illuminant such that the display of a neutral reflectance surface has equal system signals and hence is shown at the balance point of the display, D65. This ensures that the capability of each drive signal is fully used, whether it be a system signal or a display signal. Whenever the scene contains a colour which is metamerically equal to one of the system primaries, only that system primary signal will be non-zero and will be unity if the luminance of the scene colour is numerically equal to the relevant Y term in equation 2c. Similar arguments hold for the display. This property does not necessarily apply in the multi-primary display described below.

3. Multi-primary analysis method

The multi-primary problem can be overcome by dissecting the colour gamut of the display into triangles formed by sets of three of the display primaries, and using any analysis which produces only positive drive signals. Unfortunately, not all of the triangles thus formed will contain the balance point of the system and so the mathematics of Section 2 cannot be used directly, also it may be difficult to set up the display device in practice. For a multi-primary display there are several solutions to this.

The display may be made using three primaries at a time forming triangles which do not overlap; overlapping triangles are then required only for setting up the display. This approach, of using contiguous non-overlapping triangles, might cause some difficulties if the implementation of the following mathematics is not sufficiently accurate; noise could cause fast switching between triangles resulting in unfamiliar effects.

As an alternative, overlapping triangles can be used and the switching between triangles can then employ hysteresis to avoid these effects. It is possible to calculate an analysis for a triad which uses two real primaries and one synthetic primary, made by linearly mixing two others.

The calculation processes required to produce the matrices which connect the transmission signals with the display primaries is as described in Section 2. The concept of balancing each display primary triad individually to an illuminant is retained, even though not all of the triads contain the white point. Any triad not containing the white point will produce a column in the display matrix containing only negative numbers, and the appropriate multiplier (l,m or n) is negative. This is only a mathematical problem, and does not render the problem insoluble as is shown below.

The matrices are found as follows:

First produce the system transmission and display matrices using the method described in Section 2 above (balancing to the illuminant, D65). This gives the matrices [Ms] and [Mt].

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \text{3a}$$

$$\begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} = \begin{bmatrix} & & \\ & Mt & \\ & & \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \text{3b}$$

The system matrix [Ms] is not required except for the production of the transmission matrix [Mt], however the multipliers ls ms and ns may be of use later in the balancing of analyses together.

Then form the matrix for the real display primaries.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Xp1 & Xp2 & Xp3 & Xp4 & \ldots \\ Yp1 & Yp2 & Yp3 & Yp4 & \ldots \\ Zp1 & Zp2 & Zp3 & Zp4 & \ldots \end{bmatrix} \cdot \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \\ etc \end{bmatrix} \qquad \text{3c}$$

This is actually formed, at this time, from the chromaticity coordinates and unknown scalers k.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} k1*xp1 & k2*xp2 & k3*xp3 & k4*xp4 & \ldots \\ k1*yp1 & k2*yp2 & k3*yp3 & k4*yp4 & \ldots \\ k1*zp1 & k2*zp2 & k3*zp3 & k4*zp4 & \ldots \end{bmatrix} \cdot \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \\ etc \end{bmatrix} \qquad \text{3d}$$

Take sets of three of the display primaries and form a 3 by 3 display matrix [Md] from the relevant columns from the full display matrix of equation 3d, thus for example:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} k1*xp1 & k2*xp2 & k3*xp3 \\ k1*yp1 & k2*yp2 & k3*yp3 \\ k1*zp1 & k2*zp2 & k3*zp3 \end{bmatrix} \cdot \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} \qquad \text{3e}$$

and balance this to the white point (D65) using the procedure of Section 2. This will give the display matrix [Mpd] for these primaries and its inverse [Mpc].

$$\begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} = \begin{bmatrix} & & \\ & Mpd & \\ & & \end{bmatrix}^{-1} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$= \begin{bmatrix} & & \\ & Mpc & \\ & & \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad 3f$$

The linear scalers k1, k2 and k3 are the values l, m and n, which are of use in relating analyses to each other. Note that if the triad of primaries does not contain the white point, then one of the scalers will be negative and its column of the display matrix is negative. Although this appears to be an impossibility, implying that the primary must ingest light in order to produce the white point, the problem will disappear in the matching process to be described below.

Finally multiply the matrix from equation 3f by [Ms] to obtain the display transfer matrix for these primaries:

$$\begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} = \begin{bmatrix} & & \\ & Ms & \\ & & \end{bmatrix} \cdot \begin{bmatrix} & & \\ & Mpc & \\ & & \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

$$= \begin{bmatrix} P1rs & P1gs & P1bs \\ P2rs & P2gs & P3bs \\ P3rs & P3gs & P3bs \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

$$= \begin{bmatrix} & & \\ & Mx & \\ & & \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad 3g$$

and this is the linear matrix which must be included in the display device to drive these primaries for this solution. The matrix comprises the tristimulus values of Rs Gs and Bs in the colour space defined by P1 P2 and P3.

Note that all of these matrices will result in unity display primary drives at D65 since all the sets of three primaries are balanced to D65, but that each primary triad has its own display matrix and thus requires the display to have different gain settings for each primary in each set. The separate solutions must now be modified so that there is one unified display matrix and each solution produces drive signals correctly scaled to it. This process eliminates all gain controls between each matrix output and the display, except for one master control per primary which is used to set up the display.

Let us suppose that there are two solutions (a and b) which use the red display primary, they have scalers la and lb derived from the mathematics of Section 2 and these multipliers are the scalers for the red primary. This means that solution a produces la units of light per unit of drive signal, while solution b produces lb units of light per unit drive. This problem can be resolved by moving the scalers into the transfer matrices [Mx] by multiplying each coefficient in turn by la or lb as appropriate; the red primary is now scaled to unity. The resultant matrices will no longer produce equal drives for the white point, so each primary drive can be further scaled such that no matrix ever produces more than unity drive for any displayed colour. Choice of this scaler is at the discretion of the designer; the red column of the unified display matrix will comprise

the chromaticity coordinates of the red primary multiplied by this new scaler. This process can be expanded to include more than two solutions, and to match all primaries as required. It is worth noting here that if any of the primary triads do not contain the white point, the resultant negative row in the transfer matrix will change sign in this process and produce sensible numbers. Examples are given in the numerical solutions in Appendix 1.

The calculation for a triad of display primaries using two real (P1, P2) and one synthetic is as follows. To illustrate the method, the synthetic primary Pm will be taken to be a linear mix of P3 and P4, in the ratio a:b.

First decide on the linear mix ratio and calculate the chromaticity coordinates of Pm:

$$\begin{aligned} xpm &= (a * xp3 + b * xp4) / (a+b) \\ ypm &= (a * yp3 + b * yp4) / (a+b) \\ zpm &= (a * zp3 + b * zp4) / (a+b) = 1 - xpm - ypm \end{aligned} \tag{3h}$$

Then proceed as before to find the display matrix and its inverse for the primaries P1 P2 and Pm, noting that the resulting scalers are k1 k2 and km. Continue to find the transfer matrix between these primaries and the system primaries. The transfer matrix can be expanded out into a 4 by 3 matrix by copying the Pm row into the P3 and P4 rows. Thus if:

$$\begin{bmatrix} P1 \\ P2 \\ Pm \end{bmatrix} = \begin{bmatrix} k00 & k01 & k02 \\ k10 & k11 & k12 \\ k20 & k21 & k22 \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \tag{3i}$$

then:

$$\begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \end{bmatrix} = \begin{bmatrix} k00 & k01 & k02 \\ k10 & k11 & k12 \\ k20 & k21 & k22 \\ k20 & k21 & k22 \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \tag{3j}$$

The scalers for P3 and P4 are k3 and k4 and are given by:

$$k3 = km * a/(a+b) \qquad k4 = km * b/(a+b) \tag{3k}$$

This matrix and scalers can then be dealt with precisely as for the conventional 3 by 3 matrices to produce a unified display. The proof of this expansion is as follows:

The display equation for these primaries is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} k1*xp1 & k2*xp2 & km*xpm \\ k1*yp1 & k2*yp2 & km*ypm \\ k1*zp1 & k2*zp2 & km*zpm \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ Pm \end{bmatrix}$$

$$= \begin{bmatrix} k1*xp1 & k2*xp2 & k3*xp3 & k4*xp4 \\ k1*yp1 & k2*yp2 & k3*yp3 & k4*yp4 \\ k1*zp1 & k2*zp2 & k3*zp3 & k4*zp4 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \end{bmatrix} \tag{3l}$$

From Equation 3l:

$$km*xpm = k3*xp3 + k4*xp4 \qquad km*ypm = k3*yp3 + k4*yp4 \qquad 3m$$

Solving these simultaneous equations in two unknowns, k3 and k4:

$$k3 = km * \left(\frac{xp4*ypm - xpm*yp4}{xp4*yp3 - xp3*yp4}\right) \qquad k4 = km * \left(\frac{xp3*ypm - xpm*yp3}{xp3*yp4 - xp4*yp3}\right) \qquad 3n$$

and substituting xpm and ypm from Equation 3h this can be simplified to produce the identity in Equation 3k.

A method for determining a display colour of a point in an image can therefore be implemented, in which drive signals for generating display primaries are calculated using each of a set of triads of display primaries selected so as to encompass the required display colour gamut and the drive signals from a triad producing no negative drive signals selected as the display primary drive signals.

The analysis derived above can be incorporated into a practical multiprimary display device. Fig. 4 shows one implementation using, by way of example, three analyses.

Figure 4 shows a decoding circuit for a four-primary display device 2, which generates the required four display drive signals 4 from a coded transmission signal 6 from a three-primary transmission system. The transmitted signal 6 may be a conventional colour difference/luminance signal for example. The transmission signal 6 is input to a decoder 8 which decodes the signal to produce Rs, Gs and Bs system primary signals 10, and may remove any non-linearities if required. These linear Rs, Gs and Bs signals are input to three parallel matrix arithmetic units 12,14,16, each of which calculates linear display primary drive signals based on a respective triad of the display primaries. A logic unit 18 is connected to each matrix unit, examines the output of each and selects a set which, for each pixel, has only positive output signals (for a black pixel the choice is immaterial). Respective matrix outputs are input to switches 20,22,24 controlled by the logic unit and hence via a four-way gain controller 26 and a four-way non-linearity corrector 28 for supply to the display device 2 as display primary drive signals 4.

If the triads of display primaries for the matrix analyses are contiguous but do not overlap, the logic unit only has one choice of all-positive drive signals. If the triads overlap there is ambiguity and so hysteresis can be used to reduce the frequency of switching between different triad analyses. The selected analysis operates the display device through any non-linearity needed to linearize it; each drive signal has only one gain control which is used only in the setting up procedure for white balancing.

The setting up procedure is fairly straight forward. One way to do this is to use a split-screen technique to allow the simultaneous display of overlapping analyses and adjusting the primary gains to obtain the balance point in each analysis. For four primaries two overlapping sets suffice, for five primaries three sets are required etc. Only when each analysis is producing the chromaticity of the white point will they produce the same luminance, and at this setting the entire display is "balanced".

It is a curiosity of the mathematics that a practical external reference of the white point is not required since it is built into the mathematics. However, it should be noted that this analysis functions only when the display has a linear transfer characteristic, or when any display device non-linearity is fully corrected after the matrices. If the display non-linearity is not corrected, then the several analyses will not grey scale track together since the "gamma correctors" will not be equally driven. Thus applying a grey scale in a split-screen arrangement as mentioned above will reveal errors of linearity and this may provide an easy way of diagnosing mistracking of the correctors.

5. Method of use of a practical four-primary display

A set of numerical solutions is given in Appendix1, using display primaries Rd, Bd, G1d, G2d and Md, a mixture at Rd and Bd.

5.1 Non-overlapping solutions

There are two methods using non-overlapping analyses.

The first uses the Rd G1d Bd analysis and switches to the G1d G2d Bd analysis if Rd is negative, switching back to Rd G1d Bd if G2d is negative. The second uses the Rd G2d Bd analysis and switches to the Rd G1d G2d analysis if Bd is negative, switching back to Rd G2d Bd if G1d is negative.

5.2 Overlapping solutions

One method of using overlapping solutions is to use the G1d Md G2d solution as the default, and to switch into the Rd G1d Bd solution if G2d is negative, or into Rd G2d Bd if G1d is negative. Hysteresis can be invoked by not switching back from either of these until the appropriate green in that analysis goes negative; for example, revert from Rd G1d Bd to G1d Md G2d only when G1d goes negative, and revert from Rd G2d Bd to G1d Md G2d only when G2d goes negative.

5.3 Setting up procedure

This is the same for both contiguous and overlapping methods. Using a split-screen technique, display the equal-drive transmission signals (Rs=Gs=Bs=1) to the Rd G1d Bd and Rd G2d Bd analyses, and adjust the display primary gain controls both to produce D65 from each analysis. It is worth noting that this will not be easy, since if the mixture of red to blue is not correct, it will not be possible to get D65 in either analysis, however if that mixture is correct both analyses can produce D65 by adjustments of G1d and G2d. At white balance the two analyses not only produce D65, but they produce it at the same luminance, thus it might be possible to set up the display without external reference to D65 since that colour is generated by both analyses only when their luminances are identical, and this condition is easy to check by eye.

The resultant display is not as efficient as a conventional three primary device, since peak white can be achieved with one primary switched off. In fact, the efficiency can be calculated since the maximum luminance achievable by the display is the sum of the Y row from equation 4e and the maximum luminance of the balanced white is 1, thus the luminous efficiency is:

$$\text{Eff} = \frac{1}{(0.3378 + 0.7185 + 0.6277 + 0.0386)}$$

or 58%. A different choice of primaries would give a different result and so could produce a display with greater luminous efficiency.

6 Application to non-linear systems

Any non-linearity in the signal path from the display matrices to output light will result in differential level-dependant colour distortions between the several analyses, so correction for the display non-linearity must take place between the matrix outputs and the primary drives. If the overall system (light in to light out) is required to have an overall non-linear transfer characteristic then circuits having this characteristic must be interposed between the linear system signals (Rs Gs and Bs) and the inputs to the matrices.

6.1 Non-linear application of 4-primary display

In a television system which employs a constant-luminance coding system and more than three display primaries, some of the complexity of the decoder can be simplified by the adoption of YRB signal handling. In particular, since it is not necessary to decode the G signal there is no need to linearize the Y R and B before matrixing to the display primaries. All that is required is that the Y R and B signals are raised to the appropriate power for the display before matrixing. The proof is as follows:

If the system display matrix is:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} & & \\ & S & \\ & & \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

then the luminance equation is:

$$Y = s10 * Rs + s11 * Gs + s12 * Bs$$

where the coefficient suffices refer to the row and column of the matrix. Thus:

$$Gs = (Y - s10 * Rs - s12 * Bs) / s11 \qquad 6a$$

The transfer matrix relating the display primaries P1 P2 P3... to the system primaries Rs Gs and Bs is:

$$\begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \\ .. \end{bmatrix} = \begin{bmatrix} \\ \\ D \\ \\ ... \end{bmatrix} . \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

Substituting Gs from equation 6a into this gives:

$$\begin{bmatrix} P1 \\ P2 \\ P3 \\ P4 \\ .. \end{bmatrix} = \begin{bmatrix} \\ \\ M \\ \\ ... \end{bmatrix} . \begin{bmatrix} Rs \\ Y \\ Bs \end{bmatrix}$$

where the matrix coefficients m are given by:

$$mp0 = dr0 - dr1 * s10 / s11$$
$$mp1 = dr1 / s11$$
$$mp2 = dr2 - dr1 * s10 / s11$$

where m d and s refer to the coefficients of the matrices [M] [D] and [S] respectively and suffix r deontes the row of the matrix.

Thus a linear matrix can be calculated which connects the display primaries to the transmission primaries as Y R and B, and the G signal is not required.

In a typical system the transmission power law is 0.45, driving a display with a law of 2.8 and thus having an overall law of 1.26. The Y' R' B' signals in the decoder are already raised to 0.45 by the coding system, and should be further raised to power 2.8 (1.26/0.45) before application to the matrices so that these signals are linearly related to light emitted by the display. Correction of 1/2.8 (inverse of the display) must be applied at the output of the display matrices if the several matrices are to produce identical colours in overlapping areas.

For a typical system, a power law of 0.45 is applied at the studio equipment, the display is assumed to have a power law of 2.8 and the overall system characteristic is therefore 1.26 (0.45 * 2.8), these figures are based upon standard practice with cathode ray displays. To achieve this in a multi-primary display, the input signals to the display matrices must be linearly related to the output light and thus must be related to the system signals Rs Gs and Bs by the power law 1.26. This implies that for a conventionally coded system, three non-linearities are required before the matrices and one for each display primary after matrices; for a constant-luminance coded system three non-linearities are required in the decoder, three more before the matrices and one for each display primary after the matrices.

7. Analysis using a Fifth Display Colour.

The constraints used to solve the problem of producing four display primaries from three system primaries in Sections 1 to 6 are not the only solution. A solution using a different set of constraints will now be described which may be more suited to an effective practical implementation requiring a reduced number of non-linear circuit components. This may allow an improvement in image quality and implementation cost.

Numerical data for the following illustrative calculation are provided in Appendix 2.

Figure 5 is a chromaticity diagram, in 1931 xy coordinates, of the improved colour coding system. This shows the spectrum locus together with the locations of the three system colour primaries R_s, G_s, B_s, and the four display colour primaries, R_d, G_{1d}, G_{2d}, B_d. In the colour analysis now considered a fifth display colour, G_{3d}, is defined, formed from an approximately equal mixture of G_{1d} and G_{2d}. Inside the triangle formed by R_d, G_{3d} and B_d, colours are matched by the appropriate mixture of these

three primaries. Outside this triangle, colours are matched by a mixture of R_d, G_{1d} and G_{3d} or G_{2d}, G_{3d} or B_d, whichever is more appropriate.

7.1. Inside the R_s G_{3d} B_d triangle

The main function of any television system is to regenerate, at the receiver, an approximation to the colour of the original object. For the improved colour coding system considered here, if the XYZ tristimulus values of the original object were X_o, Y_o and Z_o, the approximation will consist of varying amounts of the transmission primaries R_s, G_s and B_s, in proportions such that the XYZ tristimulus values of the resultant mixture match those of the original colour. The chromaticity coordinates of the transmission primaries are defined in the system specification, however, so the amounts of each required to match the original object, A_{rs}, A_{gs} and A_{bs} lumens respectively, can be determined as follows:

$$\begin{pmatrix} X_o \\ Y_o \\ Z_o \end{pmatrix} = M_s \cdot \begin{pmatrix} A_{rs} \\ A_{gs} \\ A_{bs} \end{pmatrix} = \begin{Bmatrix} X_{rs}/Y_{rs} & X_{gs}/Y_{gs} & X_{bs}/Y_{bs} \\ 1 & 1 & 1 \\ Z_{rs}/Y_{rs} & Z_{gs}/Y_{gs} & Z_{bs}/Y_{bs} \end{Bmatrix} \cdot \begin{pmatrix} A_{rs} \\ A_{gs} \\ A_{bs} \end{pmatrix}$$

where X_{rs}, Y_{rs}, Z_{rs} are the xyz chromaticity coordinates of the R_s primary

etc. Substituting the correct values into this equation gives:

$$\begin{vmatrix} \\ M_s \\ \\ \end{vmatrix} = \begin{vmatrix} 2.2429 & 0.0000 & 4.8485 \\ 1.0000 & 1.0000 & 1.0000 \\ 0.0006 & 0.0000 & 27.8215 \end{vmatrix} . \begin{vmatrix} A_{rs} \\ A_{gs} \\ A_{bs} \end{vmatrix}$$

and hence:

$$\begin{vmatrix} A_{rs} \\ A_{gs} \\ A_{bs} \end{vmatrix} = \begin{vmatrix} \\ M_s \\ \\ \end{vmatrix}^{-1} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} = \begin{vmatrix} 0.4459 & 0.0000 & -0.0777 \\ -0.4459 & 1.0000 & 0.0418 \\ 0.0000 & 0.0000 & 0.0359 \end{vmatrix} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix}$$

Normally, the values A_{rs}, A_{gs} and A_{bs} are weighted by three coefficients, l_s, m_s and n_s respectively to form three normalised coefficients a_{rs}, a_{gs} and a_{bs} whose values are all unity at the specified white point (D65). Substituting in the correct XYZ values for one lumen of D65 illumination:

$$\begin{vmatrix} A_{rs} \\ A_{gs} \\ A_{bs} \end{vmatrix} = \begin{vmatrix} \\ M_s \\ \\ \end{vmatrix}^{-1} . \begin{vmatrix} 0.9505 \\ 1.0000 \\ 1.0891 \end{vmatrix} = \begin{vmatrix} 0.4459 & 0.0000 & -0.0777 \\ -0.4459 & 1.0000 & 0.0418 \\ 0.0000 & 0.0000 & 0.0359 \end{vmatrix} . \begin{vmatrix} 0.9505 \\ 1.0000 \\ 1.0891 \end{vmatrix}$$

$$= \begin{vmatrix} 0.3392 \\ 0.6217 \\ 0.0391 \end{vmatrix} = \begin{vmatrix} 1/l_s \\ 1/m_s \\ 1/n_s \end{vmatrix}$$

And hence:

$$\begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} = \begin{vmatrix} l_s A_{rs} \\ m_s A_{gs} \\ n_s A_{bs} \end{vmatrix} = \begin{vmatrix} 2.9482 \; A_{rs} \\ 1.6085 \; A_{gs} \\ 25.5548 \; A_{bs} \end{vmatrix}$$

It is then possible to define two new matrices, such that:

$$\begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} = \begin{vmatrix} \\ m_s \\ \\ \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} = \begin{vmatrix} 0.7607 & 0.0000 & 0.1897 \\ 0.3392 & 0.6217 & 0.0391 \\ 0.0002 & 0.0000 & 1.0887 \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} \qquad \text{7a}$$

and:

$$\begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} = \begin{vmatrix} \\ m_s \\ \\ \end{vmatrix}^{-1} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} = \begin{vmatrix} 1.3146 & 0.0000 & -0.2291 \\ -0.7171 & 1.6085 & 0.0672 \\ -0.0003 & 0.0000 & 0.9186 \end{vmatrix} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix}$$

Similar equations can be used to derive X_o, Y_o and Z_o in terms of the display primaries R_d, G_{3d} and B_d (N.B. in this instance R_d and B_d are the same as R_s and B_s, but this has not been reflected in the analysis, in order to keep it more general). Thus:

$$\begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} = \begin{vmatrix} \\ m_d \\ \\ \end{vmatrix} . \begin{vmatrix} a_{rd} \\ a_{g3d} \\ a_{bd} \end{vmatrix} = \begin{vmatrix} 0.6615 & 0.1126 & 0.1763 \\ 0.2950 & 0.6687 & 0.0364 \\ 0.0002 & 0.0774 & 1.0115 \end{vmatrix} . \begin{vmatrix} a_{rd} \\ a_{g3d} \\ a_{bd} \end{vmatrix}$$

and:

$$\begin{vmatrix} a_{rd} \\ a_{g3d} \\ a_{bd} \end{vmatrix} = \begin{vmatrix} \\ m_d \\ \\ \end{vmatrix}^{-1} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} = \begin{vmatrix} 1.6193 & -0.2411 & -0.2736 \\ -0.7172 & 1.6086 & 0.0671 \\ 0.0550 & -0.1238 & 0.9847 \end{vmatrix} . \begin{vmatrix} X_o \\ Y_o \\ Z_o \end{vmatrix} \qquad \text{7b}$$

The weighting coefficients, l_d, m_d, n_d in this case are given by:

$$\begin{vmatrix} l_d \\ m_d \\ n_d \end{vmatrix} = \begin{vmatrix} 3.3904 \\ 1.4955 \\ 27.5055 \end{vmatrix} \qquad 7c$$

Equations 7a and 7b can then be combined to yield the relationship defining the display drive signals a_{rd}, a_{g3d} and a_{bd} in terms of the decoded transmission signals a_{rs}, a_{gs} and a_{bs}:

$$\begin{vmatrix} a_{rd} \\ a_{g3d} \\ a_{bd} \end{vmatrix} = \begin{vmatrix} & \\ m_d & \\ & \end{vmatrix}^{-1} . \begin{vmatrix} & \\ m_s & \\ & \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs}. \\ a_{bs} \end{vmatrix} = \begin{vmatrix} 1.1500 & -0.1499 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & -0.0766 & 1.0766 \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} \qquad 7d$$

7.2 Inside the R_d G_{3d} G_{1d} triangle

For colours falling inside the triangle formed by the R_d, G_{3d} and G_{1d} primaries, the value of a_{bd} calculated from equation 11 above will be negative. Because it is not possible to generate negative light in a display, it is necessary to use an alternative method of colour analysis if colour reproduction errors are to be avoided. In this instance, it would seem sensible to match X_o, Y_o and Z_o by mixtures of R_d, G_{3d} and G_{1d}, rather than R_d, G_{3d} and B_d as in the previous section. By following the same procedure as that given in the previous section, therefore, it is possible to derive the revised set of display drive signals, a'_{rd}, a'_{g3d} and a'_{g1d}:

$$\begin{vmatrix} a'_{rd} \\ a'_{g3d} \\ a'_{g1d} \end{vmatrix} = \begin{vmatrix} 1.1500 & -0.3700 & 3.0942 \\ 0.0000 & -0.2457 & 17.5128 \\ 0.0000 & 1.3386 & -18.8190 \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} \qquad 7e$$

(N.B. In this instance the weighting coefficients l_d, m_d and n_d have not been recalculated from the values used in section 2.1. This is in order to avoid the need for different gains in practical realisations of this method. The factor m_d has been applied to both the a'_{g3d} and a'_{g1d} signals - in this case n_d is not required. It should be noted, however, that equal drive signals a'_{rd}, a'_{g3d}, a'gld will no longer match to D65).

By inspection of equations 7d and 7e it can be noted that:

$$a'_{g1d} = -17.4804\ a_{bd} \qquad 7f1$$

$$a'_{rd} = a_{rd} + 2.8741\ a_{bd} \qquad 7f2$$

$$a'_{g3d} = a_{g3d} + 16.2671\ a_{bd} \qquad 7f3$$

It should also be noted that:

$$a'_{bd} = 0 = a_{bd} - a_{bd} \qquad 7f4$$

Thus the above operation is equivalent to subtracting a signal of a_{bd} from the blue primary and adding signals of 2.8741 a_{bd}, 16.2671 a_{bd} and $-17.4804a_{bd}$ to the red, green$_3$ and green$_1$ primaries respectively.

7.3. Inside the G_{2d} G_{3d} B_d triangle

Colours falling in this region have negative values of a_{rd}. Following a similar procedure as in previous sections, and matching the input colour

by mixtures of G_{2d}, G_{3d} and B_d therefore:

$$\begin{vmatrix} a''_{g2d} \\ a''_{g3d} \\ a''_{bd} \end{vmatrix} = \begin{vmatrix} -7.4446 & 0.9707 & 0.0000 \\ 7.9301 & -0.0340 & 0.0000 \\ 0.4001 & -0.1257 & 1.0766 \end{vmatrix} . \begin{vmatrix} a_{rs} \\ a_{gs} \\ a_{bs} \end{vmatrix} \qquad 7g$$

As in section 7.2, the weighting coefficients used in equation 7g are the same as those used in equation 7d. By inspection of equations 7d and 7g:

$$a''_{g2d} = -6.4739\ a_{rd} \qquad 7h1$$

$$a''_{g3d} = a_{g3d} + 6.8961\ a_{rd} \qquad 7h2$$

$$a''_{bd} = a_{bd} + 0.3479\ a_{rd} \qquad 7h3$$

$$a''_{rd} = 0 = a_{rd} - a_{rd} \qquad 7h4$$

2.4. Formation of the final combined display drive signals

The final display drive signals for the R_d and B_d primaries are formed by combining the signals of equations 7d, 7f and 7h:

$$a'''_{rd} = a_{rd} - (\ a_{rd}\ )_{ardso} + 2.8741(\ a_{bd}\ )_{abdso}$$

$$a'''_{bd} = a_{bd} - (\ a_{bd}\ )_{abdso} + 0.3479(\ a_{rd}\ )_{ardso}$$

In order to form the G_{1d} and G_{2d} drive signals, account must also be taken of the value of the G_{3d} primary. In section above, it was stated that the G_{3d} primary was formed from approximately equal proportions of G_{1d} and G_{2d}. The exact proportions were adjusted so that the chromaticity coordinates of G_{3d} were exactly mid-way between those of G_{1d} and G_{2d}; i.e. the relative luminances are mixed in the ratio 0.7543 : 0.8029 - the ratio of their y chromaticity coordinates. Thus a given amount, A_{g3d} lumens, of the G_{3d} primary may be matched by A_{g1d} lumens of G_{1d} added to A_{g2d} lumens of G_{2d}, where:

$$A_{g1d} = \frac{0.7543}{2 * 0.7786} . A_{g3d} = 0.4844\ A_{g3d}$$

$$A_{g2d} = \frac{0.8029}{2 * 0.7786} . A_{g3d} = 0.5156\ A_{g3d}$$

Since the weighting factors applied to G_{1d}, G_{2d} and G_{3d} are all equal, the same equations can be applied to the normalised values a_{g1d} etc:

$$a_{g1d} = 0.4844\ a_{g3d}$$

$$a_{g2d} = 0.5156\ a_{g3d}$$

Adding together the various contributions, therefore:

$$a'''_{g3d} = a_{g3d} + 6.8961(\ a_{rd}\ )_{ardso} + 16.2671(\ a_{bd}\ )_{abdso}$$

And hence:

$$a'''_{g1d} = 0.4844\ a'''_{g3d} - 17.4804(\ a_{bd}\ )_{abdso}$$

$$= 0.4844\ a_{g3d} + 3.3405(\ a_{rd}\ )_{ardso} - 9.6006(\ a_{bd}\ )_{abdso}$$

$$a'''_{g2d} = 0.5156\, a'''_{g3d} - 6.4739(a_{rd})_{ardso}$$

$$= 0.5156\, a_{g3d} - 2.9182(a_{rd})_{ardso} + 8.3873(a_{bd})_{abdso}$$

A method for determining a display colour of a point in an image can thus be implemented. This method in more general terms uses four display primaries, i.e. first, second, third and fourth primaries lying in sequence at consecutive, adjacent corners of a quadrilateral in a chromaticity diagram, and comprises the following steps:

(A) a fifth, imaginary, display primary is determined, being a linear combination of the third and fourth display primaries,

(B) signals for generating first, second and fifth display primaries are calculated using a triad of display primaries comprising the first, second and fifth display primaries,

(C) if the signals calculated in (B) are all either zero or positive, the signals for the first and second display primaries are used to form display primary drive signals, and drive signals for the third and fourth display primaries are calculated by using the signal for the fifth display primary to calculate drive signals for the third and fourth display primaries according to the linear relationship between them,

(D) if the signal calculated for the first display primary is negative, display primary drive signals are initially calculated as in (C), and then the second and fourth display primary drive signals so calculated are modified by the addition of predetermined multiples of the first display primary drive signal thereto and the first display primary drive signal is set to zero,

(E) if the signal calculated for the second display primary is negative, display primary drive signals are initially calculated as in (C), and then the first and third display primary drive signals so calculated are modified by the addition of predetermined multiples of the second display primary drive signal thereto and the second display primary drive signal is set to zero.

8. Implementation in hardware

Figure 6 shows a circuit which might be used to decode the four drive signals in practice.

Incoming a_{rs}, a_{gs} and a_{bs} signals 30, which may be derived from transmitted colour difference/luminance signals, are input to a matrix arithmetic unit 32. Any non-linearity in these signals may need to be removed, for example on prior decoding of a transmitted signal. In practice, there will probably be no need to first decode the a_{rs}, a_{gs} and a_{bs} signals, a_{rd}, a_{g3d} and a_{bd} probably being formed directly from transmitted Y,R-Y,B-Y signals; this has little effect on the decoder circuit however.

The matrix arithmetic unit calculates display primary signals for Rd, G_{3d} and Bd, i.e. a_{rd}, a_{g3d} and a_{bd}. These signals are then applied to outputs 34 of the decoder circuit to form portions of the a"'rd, $a"'_{g1d}$, and $a"'_{g2d}$, and $a"'_{bd}$ display primary drive signals respectively. The a_{rd} and a_{bd} signals from the matrix unit are however also applied to an 'ideal diode' circuit 36 and the resultant rectified signals combined at the circuit outputs 34 with the signals output directly from the matrix unit to form contributions to the final decoded a"'rd, $a"'_{g1d}$, $a"'_{g2d}$, and $a"'_{bd}$ display primary drive signals.

Two factors are worth noting on this circuit. The first is that the diodes are being used simply as switches, and not as calibrated non-linearities. This should make the circuit easy to duplicate. The second factor to note is that the diode outputs are added into all four of the output colour channels. This is equivalent to matching negative values of R_d by the appropriate values of G_{1d}, G_{2d} and B_d. The circuit is therefore quasi-linear in operation, in that there is no internal clipping involved. The only clipping that is present is in the display itself - negative values of a'''_{rd} etc cannot be reproduced, and are hence clipped to black. This quasi-linear response is largely responsible for the well-behaved response to colours outside the reproducible gamut - see following section.

9. Performance for colours outside the realisable gamut

The circuit of Figure 6 is capable of accurately reproducing any colour occurring within the colour gamut set by R_d, G_{1d}, G_{2d} and B_d. It is important, however, to also consider what happens to colours outside this gamut; the system should "fail gracefully" under such conditions, and should not behave in an unacceptable manner.

As can be seen from Figure 7, the complete colour spectrum outside the reproducible gamut can be split into four identifiable regions. In region 1, a'''_{g2d} is negative. Since negative values of G_{2d} cannot be produced, the colour is displayed as if it were mixed with a sufficient amount of G_{2d} to bring it to the line $G_{1d}R_d$. In regions 2 and 3, the colours cannot be reproduced by the coding system itself (a_{gs} or a_{rs} becomes negative); the display system introduces no further errors, and the displayed colours are distorted towards the G_s or R_s primaries respectively. Region 4 is more complex, however, and must be further sub-divided into three areas, depending on the relationship of the colour being transmitted to the lines R_dG_{3d} and B_dG_{3d}.

These sub-regions are shown enlarged in Figure 8. In sub-region 4a, a_{bd} is negative and a_{rd} is positive. The operations of equation 16a, however, result in a value of a'''_{rd} which is negative (a'''_{bd} becoming zero). Thus the displayed colour shifts towards the R_d primary.

Similarly in sub-region 4c, a_{bd} is positive and a_{rd} is negative. The corrections of equation 16b result in a zero value of a'''_{rd} and a negative value of a'''_{bd}. The colour moves towards the B_d primary.

In sub-region 4b, however, <u>both</u> a_{rd} and a_{bd} are negative. The corrected values of a'''_{rd} and a'''_{bd} are therefore also both negative. The final displayed colour is still on the line joining G_{1d} and G_{2d}, therefore, but its exact position on that line is harder to determine. In general, as the original colour moves along any particular arc AB, the displayed colour will move along the corresponding line A'B'. As the arc of colours becomes more saturated (e.g. the arc CD), so the length of the corresponding line C'D' becomes longer. In general, therefore, saturation changes in the incoming colours can produce hue changes in the reproduced colour. Nevertheless, it can be seen from Figure 8 that these hue changes are relatively minor (similar in magnitude to the hue changes that might be produced by saturation effects in present-day coding systems). Thus the performance of the four-primary display is unlikely to produce unacceptable colour errors in any part of the visible spectrum.

APPENDIX 1

Four-primary display: Numerical Solutions

This Appendix contains the numerical results for a four primary display designed for the Eureka set of primaries. The system and display primaries are listed below:

Primaries:

Rs	620nm	x=0.6195	y=0.3083	u'=0.4538	v'=0.5081
Gs		x=0.0000	y=1.0000	u'=0.0000	v'=0.6000
Bs	460nm	x=0.1440	y=0.0297	u'=0.1877	v'=0.0871
Rd	=Rs				
Bd	=Bs				
G1d	540nm	x=0.2296	y=0.7543	u'=0.0792	v'=0.5856
G2d	514nm	x=0.0328	y=0.8029	u'=0.0104	v'=0.5749
Md	(7Rd+9Bd)/16	x=0.3835	y=0.1516	u'=0.3787	v'=0.3367
Balance	D65	x=0.3127	y=0.3290	u'=0.1978	v'=0.4683

Xw=0.3127/0.3290*1.0000=0.9505   Yw=1.0000
Zw=(1-0.3127-0.3290)/0.3290*1.0000=1.0891

1 Solution for the transmission system

Denormalising gains:
Rs (l) 1.1001   Gs (m) 0.6217   Bs (n) 1.3176   A1.1

Matrix equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.7607 & 0.0000 & 0.1897 \\ 0.3392 & 0.6217 & 0.0391 \\ 0.0002 & 0.0000 & 1.0887 \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \quad \text{A1.2}$$

$$\begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} = \begin{bmatrix} 1.3146 & 0.0000 & -0.2291 \\ -0.7171 & 1.6085 & 0.0672 \\ -0.0003 & 0.0000 & 0.9186 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \text{A1.3}$$

2 Solution for display, Rd G1d Bd

Denormalising gains:
Rd 0.7877 G1d 0.9525 Bd 1.2992 A2.1

Matrix equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.5447 & 0.2187 & 0.1870 \\ 0.2429 & 0.7185 & 0.0386 \\ 0.0001 & 0.0153 & 1.0735 \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G1d \\ Bd \end{bmatrix} \qquad \text{A2.2}$$

$$\begin{bmatrix} Rd \\ G1d \\ Bd \end{bmatrix} = \begin{bmatrix} 2.1205 & -0.6381 & -0.3465 \\ -0.7173 & 1.6086 & 0.0671 \\ 0.0010 & -0.0228 & 0.9306 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \text{A2.3}$$

Transfer matrix:

$$\begin{bmatrix} Rd \\ G1d \\ Bd \end{bmatrix} = \begin{bmatrix} 1.3967 & -0.3967 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & -0.0142 & 1.0142 \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \text{A2.4}$$

3 Solution for display, Rd G2d Bd

Denormalising gains:
Rd 1.0954 G2d 0.7818 Bd 1.1621 A3.1

Matrix equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.7575 & 0.0257 & 0.1673 \\ 0.3378 & 0.6277 & 0.0345 \\ 0.0002 & 0.1284 & 0.9603 \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G2d \\ Bd \end{bmatrix} \qquad \text{A3.2}$$

$$\begin{bmatrix} Rd \\ G2d \\ Bd \end{bmatrix} = \begin{bmatrix} 1.3233 & -0.0070 & -0.2303 \\ -0.7173 & 1.6086 & 0.0671 \\ 0.0957 & -0.2151 & 1.0324 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \text{A3.3}$$

Transfer matrix:

$$\begin{bmatrix} Rd \\ G2d \\ Bd \end{bmatrix} = \begin{bmatrix} 1.0043 & -0.0043 & 0.0000 \\ 0.0000 & 1.0000 & 0.0000 \\ 0.0000 & -0.1337 & 1.1337 \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \text{A3.4}$$

4 Solution for display, Rd G1d G2d

Denormalising gains:
Rd 3.7066 G1d -8.0834 G2d 7.4151 A4.1

Matrix equations:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.5632 & -1.8561 & 0.2434 \\ 1.1429 & -6.0975 & 5.9546 \\ 0.0006 & -0.1297 & 1.2181 \end{bmatrix} \cdot \begin{bmatrix} Rd \\ G1d \\ G2d \end{bmatrix} \qquad \text{A4.2}$$

```
[ Rd]    [ 0.4585  -0.1536  0.6592]    [X]
[G1d] =  [ 0.0957  -0.2151  1.0324]  . [Y]
[G2d]    [ 0.0100  -0.0228  0.9306]    [Z]          A4.3
```

Transfer matrix:

```
[ Rd]    [ 0.2968  -0.0955  0.7987]    [Rs]
[G1d] =  [ 0.0000  -0.1337  1.1337]  . [Gs]
[G2d]    [ 0.0000  -0.0142  1.0142]    [Bs]         A4.4
```

5. <u>Solution for display, G1d G2d Bd</u>

Denormalising gains:

B1d 3.3910 G2d -2.0013 Bd 1.6497 A5.1

Matrix equations:

```
[X]    [ 0.7786  -0.0657  0.2375]    [G1d]
[Y] =  [ 2.5579  -1.6069  0.0490]  . [G2d]
[Z]    [ 0.0544  -0.3287  1.3632]    [ Bd]          A5.2

[G1d]    [ 1.3233  -0.0070  -0.2303]    [X]
[G2d] =  [ 2.1205  -0.6381  -0.3465]  . [Y]
[ Bd]    [ 0.4585  -0.1536   0.6592]    [Z]         A5.3
```

Transfer matrix:

```
[G1d]    [ 1.0043  -0.0043  0.0000]    [Rs]
[G2d] =  [ 1.3967  -0.3967  0.0000]  . [Gs]
[ Bd]    [ 0.2968  -0.0955  0.7987]    [Bs]         A5.4
```

6. <u>Solution for display, G1d Md G2d</u>

Denormalising gains:

G1d 0.4404 Md 2.1786 G2d 0.4204 A6.1

Matrix equations:

```
[X]    [ 0.1011  0.0138  0.8355]    [G1d]
[Y] =  [ 0.0071  0.0690  1.0128]  . [ Md]
[Z]    [ 0.3322  0.3375  0.3303]    [G2d]           A6.2

[G1d]    [ 7.1178  0.9753  -6.1901]    [X]
[ Md] =  [ 0.4585 -0.1336   0.6592]  . [Y]
[G2d]    [-7.4543  2.1532   5.4473]    [Z]          A6.3
```

Transfer matrix:

```
[G1d]    [ 5.7449  0.6063  -5.3512]    [Rs]
[ Md] =  [ 0.2968 -0.0955   0.7987]  . [Gs]
[G2d]    [-4.9397  1.3385   4.6012]    [Bs]         A6.4
```

Denormalising gains:

Rd 0.9531 (=2.1786*7/16) Bd 1.2255 (=2.1786*9/16) A6.5

Transfer matrix:

```
[ Rd]    [ 0.2968  -0.0955  0.7987]    [Rs]
[G1d] =  [ 5.7449   0.6063 -5.3512] .  [Gs]
[G2d]    [-4.9397   1.3385  4.6012]    [Bs]
[ Bd]    [ 0.2968  -0.0955  0.7987]              A6.6
```

7. <u>Unified display, Rd G1d G2d Bd</u>

For arbitrary reasons, the display matrix will use as denormalising gains, Rd and G2d from solution 3 (Rd G2d Bd), G1d and Bd from solution 2 (Rd Gd Bd). Each row of each transfer matrix is then multiplied by the ratio of the denormalisers for that colour in its own solution and for the unified display matrix.

Denormalising gains:

```
G1d   0.9525    Bd    1.2992
Rd    1.0954    G2d   0.7818                     A7.1
```

Unified display matrix equation:

```
[X]    [ 0.7576  0.2187  0.0257  0.1870]    [ Rd]
[Y] =  [ 0.3378  0.7185  0.6277  0.0386] .  [G1d]
[Z]    [ 0.0001  0.0153  0.1284  1.0735]    [G2d]
                                            [ Bd]   A7.2
```

Transfer matrices:

Solution 2 (Rd G1d Bd):

```
[ Rd]    [ 1.0043  -0.2852  0.0000]    [Rs]
[G1d] =  [ 0.0000   1.0000  0.0000] .  [Gs]
[G2d]    [ 0.0000   0.0000  0.0000]    [Bs]
[ Bd]    [ 0.0000   0.0000  0.0000]              A7.3
```

Solution 3 (Rd G2d Bd)

```
[ Rd]    [ 1.0043  -0.0043  0.0000]    [Rs]
[G1d] =  [ 0.0000   0.0000  0.0000] .  [Gs]
[G2d]    [ 0.0000   1.0000  0.0000]    [Bs]
[ Bd]    [ 0.0000  -0.1196  1.0142]              A7.4
```

Solution 4 (Rd G1d G2d)

```
[ Rd]    [ 1.0043  -0.3231  2.7025]    [Rs]
[G1d] =  [ 0.0000   1.1347 -9.6207] .  [Gs]
[G2d]    [ 0.0000  -0.1347  9.6207]    [Bs]
[ Bd]    [ 0.0000   0.0000  0.0000]              A7.5
```

Solution 5 (G1d G2d Bd)

$$\begin{bmatrix} Rd \\ G1d \\ G2d \\ Bd \end{bmatrix} = \begin{bmatrix} 0.0000 & 0.0000 & 0.0000 \\ 3.5754 & -0.0155 & 0.0000 \\ -3.5754 & 1.0155 & 0.0000 \\ 0.3769 & -0.1212 & 1.0142 \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix} \qquad \text{A7.6}$$

Solution 6 (G1d Md G2d)

$$\begin{bmatrix} Rd \\ G1d \\ G2d \end{bmatrix} = \begin{bmatrix} 0.2583 & -0.0831 & 0.6949 \\ 2.6560 & 0.2803 & -2.4740 \\ -2.6960 & 0.7197 & 2.4740 \end{bmatrix} \cdot \begin{bmatrix} Rs \\ Gs \\ Bs \end{bmatrix}$$

APPENDIX 2

Colorimetric data for the four-primary system

System primaries:

Rs	620 nm	x= 0.6915	y= 0.3083	(u'= 0.5203 v'= 0.5219)
Gs		x= 0.0000	y= 1.0000	(u'= 0.0000 v'= 0.6000)
Bs	460 nm	x= 0.1440	y= 0.0297	(u'= 0.1877 v'= 0.0871)

Display primaries:

Rd	= Rs	x = 0.6915	y = 0.3083
G1d	540 nm	x = 0.2296	y = 0.7543
G2d	514 nm	x = 0.0328	y = 0.8029
G3d		x = 0.1312	y = 0.7786
Bd	= Bs	x = 0.1440	y = 0.0297

Balance white point:

D65	x = 0.3127	y = 0.3290	
	x = 0.9505	y = 1.0000	z = 1.0891

Weighting factors:

ls	2.9482	ld	3.3904
ms	1.6085	md	1.4955
ns	25.5548	nd	27.5055

34834.spec

Claims:

1. A method for decoding a signal defining a video image in terms of n independent system primaries to produce a display signal using m independent display primaries, where m>n.

2. A method according to claim 1, in which at least one of the system primaries is spectral or super-spectral.

3. A method according to claim 1 or claim 2, in which for each colour to be displayed, display primary drive signals are calculated in terms of a triad of three display primaries selected from the available m display primaries, or from one or more additional imaginary display primaries each calculated as linear combinations of two of the m display primaries, a triad comprising three display primaries of which none can be formed from a linear combination of the other two.

4. A method according to claim 3, in which more than one triad of display primaries is required to calculate display primary drive signals for all colours within an available gamut of display colours.

5. A method according to claim 4, in which the triads of display primaries are selected so that each colour to be displayed can only be defined in terms of the display primaries of one of the triads.

6. A method according to claim 4, in which the triads of display primaries are selected so that they overlap, so that at least one of the colours to be displayed can be defined in terms of the display primaries of two or more triads.

7. A method according to any of claims 4 to 6, in which four display primaries lie at the corners of a quadrilateral on a chromaticity diagram.

8. A method according to claim 7, in which n = 3, the three system primaries lying at the corners of a triangle on a

chromaticity diagram, first and second display primaries are approximately matched to first and second system primaries respectively, and third and fourth display primaries lie in the chromaticity diagram on or near sides of the triangle defined by the system primaries between the first and third system primaries and second and third system primaries respectively.

9. A method according to claim 7 or claim 8, in which at least the third system primary is spectral or super-spectral.

10. A method according to any of claims 4 to 9, in which four display primaries are used (m=4), the first, second, third and fourth display primaries lying at corners taken in order around the circumference of a quadrilateral in a chromaticity diagram, the method comprising the following steps to determine a display colour of a point in an image;

(A) a fifth, imaginary, display primary is determined, being a linear combination of the third and fourth display primaries,

(B) signals for generating first, second and fifth display primaries are calculated using a triad of display primaries comprising the first, second and fifth display primaries,

(C) if the signals calculated in (B) are all either zero or positive, the signals for the first and second display primaries are used to form display primary drive signals, and drive signals for the third and fourth display primaries are calculated by using the signal for the fifth display primary to calculate drive signals for the third and fourth display primaries according to the linear relationship between them,

(D) if the signal calculated for the first display primary is negative, display primary drive signals are initially calculated as in (C), and then the second and fourth display primary drive signals so calculated are modified by the addition of predetermined multiples of the first display primary drive signal thereto and the first display primary drive signal is set to zero,

(E) if the signal calculated for the second display primary is negative, display primary drive signals are initially calculated as in (C), and then the first and third display

primary drive signals so calculated are modified by the addition of predetermined multiples of the second display primary drive signal thereto and the second display primary drive signal is set to zero.

11. A method according to any of claims 4 to 9, in which to determine a display colour of a point in an image, drive signals for generating display primaries are calculated using each of a set of triads of display primaries selected in order to encompass the required display gamut and the drive signals from a triad producing no negative drive signals are selected as the display primary drive signals.

12. A method according to claim 11, in which at least two of the selected triads overlap, the principle of hysteresis being used to control drive signal selection for the colours of neighbouring points in an image or the colours of the same point in successive images to limit the frequency of switching between triads for the generation of drive signals.

13. Video display apparatus comprising;

inputs for receiving input signals coded using n system primaries;

display means for displaying an image using m display primaries, where m > n, and;

decoder means coupling the inputs and the display means for decoding the input signals to produce display primary drive signals.

14. Apparatus according to claim 13, in which for a colour to be displayed the decoder means evaluates display primary drive signals in terms of at least one triad of three display primaries selected from the available m display primaries or from one or more additional imaginary display primaries determined as linear combinations of two of the m display primaries, each triad comprising three display primaries of which none can be formed from a linear combination of the other two.

15. Apparatus according to claim 14, in which more than one

triad of display primaries is required to display all colours within an available gamut of display colours.

16. Apparatus according to claim 15, in which the triads of display primaries are contiguous and do not overlap.

17. Apparatus according to claim 15, in which the triads of display primaries overlap, the decoder means employing hysteresis to reduce switching between triads.

18. Apparatus according to any of claims 15 to 17, in which the decoder means comprises;

matrix arithmetic means for calculating display primary drive signals from the input signals based on each selected triad of display primaries;

logic means coupled to the arithmetic means for detecting the presence of negative drive signals calculated by the arithmetic means; and

switch means connected to the output of the arithmetic means and responsive to the logic means to switch to the display means only selected display primary drive signals based on one of the triads for which all the drive signals calculated are positive.

19. Apparatus according to claim 18, in which the logic means comprises means for using hysteresis to control drive signal selection of the colours of neighbouring points in an image or the colours of the same point in successive images to limit the frequency of switching between drive signals generated using different triads.

20. Apparatus according to any of claims 15 to 17, in which the display means uses four display primaries (m=4) which lie at the corners of a quadrilateral in a chromaticity diagram, the first, second, third and fourth display primaries lying at corners taken in order around the circumference of the quadrilateral, and an imaginary fifth display primary which is a linear combination of the third and fourth display primaries,

and in which the decoder means comprises;

a matrix arithmetic means for calculating first, second,

and fifth display primary signals using a triad defined by the first, second and fifth display primaries;

means for apportioning the fifth display primary signal into signals for the third and fourth display primaries;

means for multiplying the signals generated by the arithmetic means for the first and second display primaries by predetermined fixed coefficients and for sensing the sign (positive or negative) of the signals; and

means for adding the multiplied first and second display primary signals, depending on their sign, to the first, second, third and fourth display primary signals to produce four display primary drive signals for driving the display unit.

21. Apparatus according to any of claims 13 to 20, comprising a non-linearity decoder for substantially removing non-linearity from the input signals received before they are input to the decoder means.

22. Apparatus according to any of claims 13 to 21, comprising a non-linearity coder coupled between the decoder means and the display means for applying any required non-linearity to the display primary drive signals.

23. Video display apparatus decoder means substantially as described herein with reference to figure 4.

24. Video display apparatus decoder means substantially as described herein with reference to figure 6.

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35

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Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii)

Search Examiner
MISS S E WILLCOX

Date of completion of Search
29 DECEMBER 1993

Documents considered relevant following a search in respect of Claims :-
1, 13

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Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2260669 A	(FUJI XEROX)	1, 13
X	GB 2258783 A	(DATA PRODUCTS)	1, 13
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